20-15 SOIL LIQUEFACTION AND LATERAL SPREADING ANALYSIS GUIDELINES

Introduction

Seismically induced soil liquefaction and associated ground failure, particularly when accompanied by lateral spreading, has caused substantial damage to bridges in past earthquakes. It can significantly affect the design of bridge components such as bents and abutments. The effects may be mitigated through soil improvements or structural measures. Projects with potentially liquefiable soil require close collaboration between the bridge designer and the geotechnical designer.

Potential for soil liquefaction and associated ground failure such as lateral spreading are typically identified during the project foundation investigation phase and are included with the Foundation Report provided by the geotechnical designer. Identification of liquefaction potential may occur at the planning study phase if adequate geotechnical information is available, or may not occur until the subsurface site investigation is completed during the design phase. The reader is referred to *MTD 20-14*, in which the liquefaction and lateral spreading causes, effects and classifications, as well as their impact on project delivery and cost, are discussed.

With respect to structure design, the effects of liquefaction and associated lateral spreading and how these effects should be combined with inertial load effects, is a complex issue and the subject of considerable research. The intent of the design process outlined in this memo is to provide the designer with simplified procedures and guidelines that prudently consider the effects of seismically induced liquefaction and lateral spreading.

Analysis Guidelines

Liquefaction can have a significant effect on the design of a structure, especially with regard to the structure foundation. Obtaining geotechnical data in a timely manner is critical. For a structure widening, the As-built Log of Test Borings can be used to generate the preliminary liquefaction data such as p-y and t-z curves and lateral spreading pressures. P-y and t-z/q-z curves, which are commonly used for analysis and design of deep foundations, represent force-displacement interactions between the pile and the surrounding soil under lateral and axial loading conditions, respectively.

For new bridges, adequate geotechnical data may not be available until the subsurface site investigation is completed, which typically takes place later in the design process. It is necessary to coordinate with the geotechnical designer in order to expedite the subsurface site investigation and have the liquefaction potential assessment as early as possible in the design process. See *Attachment-1 in MTD 20-14*.

There are three main effects of liquefaction and ground failure/lateral spreading on the design and behavior of bridge structures. One or more of these effects can be present at a particular bridge site depending on the subsurface conditions and seismicity of the site:

1. Reduction in soil lateral stiffness and strength. The lateral resistance/strength of the liquefied soil is significantly lower than that of non-liquefied soil. The reduced stiffness and strength will affect the calculated structural displacement demands, displacement capacities, and foundation design forces. The designer should analyze the structure considering both the liquefied and non-liquefied cases.

2. Downdrag load and foundation settlement. Soil liquefaction may impart downdrag loads on the foundation. Where the liquefiable layer is overlain by compacted soil the downdrag load on the piles from the crust shall be considered. The structural strength of the pile must be adequate to resist the additional downdrag load. Since the downdrag force develops as pore water pressure in the liquefied layer is dissipated, which generally happens after the strong motion has significantly subsided, it should be combined with service loads and not with the inertial forces. The downdrag load on pile foundations may cause foundation settlement. If piles are tipped into a very dense soil layer or formational rock the settlement will be small. The geotechnical designer is responsible for assessing the downdrag forces and foundation settlement.

3. Liquefaction induced lateral spreading (horizontal ground displacements) which impart large forces on the foundation. These forces are in addition to the forces resulting from inertial effects (column plastic hinging). Although there is no consensus in the research community, it is believed that the peak lateral spreading forces generally do not take place simultaneously with the peak ground motion. Several inertial and lateral spreading load combinations have been recommended and used in the past for design purposes. The analysis guidelines adopted in this memo, as outlined in the bent and abutment analysis sections and Attachment 1, should lead to a conservative design. The geotechnical designer is responsible for assessing the load due to lateral spreading.

The analysis process at the bents and abutments that incorporates liquefaction can be outlined as follows (see Attachment 1 for additional guidance):

Bent Analysis

(A) Perform a push-over analysis without liquefaction (i.e., non-liquefied p-y and t-z curves), check local/global demand/capacity in accordance with SDC requirements, redesign if necessary;

(B) Perform a push-over analysis with liquefaction (i.e., with liquefied p-y and t-z curves for the liquefied layers) and no lateral spreading, check local/global demand/capacity in accordance with SDC requirements, redesign if necessary;

(C) If lateral spreading is present, then re-analyze with liquefaction and lateral spreading force. Use 100% of the Lateral Spreading Force (LSF) for single-column bents on pile shafts and 67% of LSF for all other cases (i.e. single-column bents on pile groups, multi-column bents on shafts or pile groups, and pier walls). Proceed as follows for the appropriate foundation system;

1 - For Type-I pile shafts:

If the moment demand on the shaft due to LSF alone is less than 20% of M_p of the shaft, then check the shaft shear and end the process; if the moment demand due to LSF alone is greater than 20% but less than 30% of M_p then redesign (i.e. increase shaft strength,…) and repeat the process. However, if the moment demand is greater than 30% of M_p consider using a Type-II instead of a Type-I shaft.

2 - For Type-II pile shafts:

If the total moment demand on the shaft due to M_p of the column and LSF is less than M_p of the shaft, then check the shaft shear and end the process, otherwise redesign (i.e. increase shaft strength,…) and repeat the process.

3 - For pile groups where pile plastic hinging is not allowed:

If the total moment demand on the pile due to M_p of the column and LSF is less than M_p of the pile, check the pile shear and end the process, otherwise redesign (i.e. increase pile strength,…) and repeat the process.

4 - For pile groups where pile plastic hinging is allowed:

Formation of plastic hinges in piles is not desirable according to Caltrans current design practice. However, if the project specific design criteria allows plastic hinging in the piles, and if the moment demand on the pile due to LSF alone is less than 20% of M_p of the pile, then check the pile shear and end the process, otherwise redesign (i.e. increase pile strength) and repeat the process or consider an alternative foundation type.

When lateral spreading is present, the shear demand calculation can be complicated (nonlinear behavior, particularly for Type-1 shafts) and time consuming given the current state-of-the-practice and analysis tools. In lieu of the more complicated calculation, Attachment 1 provides a simplified and approximate expression that may be used for computing shear demand at the bents.

Abutment Analysis

When liquefaction/lateral spreading is identified at the abutment, the geotechnical designer performs the entire abutment-soil liquefaction/lateral spreading analysis and provides the designer with a pressure distribution on the abutment/pile. The designer should then include 67% of this pressure distribution with abutment gravity loads for the design of the abutment piles. These piles may be modeled and analyzed separately with the lateral spreading loads distribution included with other resultant abutment loads at top of pile. When plastic hinging is not allowed in abutment piles, the maximum pile moment demand should be less than M_p of the pile. When plastic hinging is allowed in the piles (not recommended), the maximum pile moment should be less than 120% of M_p of the pile. It should be noted that the abutment analysis described in this section is not comprehensive and future refinements may be considered.

General Guidelines

- The liquefied layer provides relatively small or no lateral resistance; one common way to model liquefaction is to use reduced p-y, and t-z soil springs, or to ignore their resistance altogether.
- When lateral spreading force is considered then the lateral resistance of soil from the ground surface to the bottom of the liquefiable layer is usually ignored (i.e. no soil springs within this zone).
- Application of lateral spreading force needs to be considered carefully in order to produce a consistent analytical model. Because inertial forces reverse direction, one needs to consider the direction that will produce the maximum demand when combined with lateral spreading forces, which in most cases are unidirectional.
- The potential for embankment soil instability at the abutment and potential mitigation measures should be discussed with the geotechnical designer and addressed in the Final Foundation Report.
- The no-liquefaction case may control the design. As plastic hinges migrate due to liquefaction, the no-splice zone must be centered on a range of possible hinge locations (this could lead to long no-splice zones that should be checked for contractibility issues).
- Spread footings on liquefiable soil should be avoided.

References

1. California Department of Transportation, *Bridge Memo to Designers 20-14*

2. California Department of Transportation, *Seismic Design Criteria*

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